

Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia

CONSTRUCTION MANAGEMENT OF POWER TRANSMISSION LINES - LOGISTICS AND CHALLENGES

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ABSTRACT: Power transmission line is an interconnection from generating stations, may it be thermal or hydro, to load centers catering for industrial, commercial and domestic consumers of electricity. It comprises of a combination of components in a multi-discipline blend of electrical, structural and geotechnical engineering. The construction of power transmission lines has always been a challenge to the power industry utilities as it involves positioning and installation of tall towers on rugged terrains, inaccessibility of land transportations in remote areas, minimizing damages to crops and paddy fields, scarcity of rentice in urban developed areas, right-of-way (wayleave) management, sensitivities of land-use, constraints pertaining to the electricity supply regulation requirements, aesthetics and environmental considerations. Managing transmission line construction logistics is a specialized craft by itself. Heavy masses of structural steelwork, construction materials for concrete foundations, reels of conductor cables, transmission line fittings and accessories, and heavy stringing machineries such as tensioners and pullers need to be transported to hilltops or swampy areas. This paper provides an informative overview of the current construction practices and the management of logistics for the installation of power transmission lines in this region, the challenges facing the utilities and regulators for a sustainable construction, and the sharing of knowledge, technical information and experience on a specialized field of engineering construction.

Keywords: Transmission line, steel tower, sag-tension, wayleave management, logistics.

1. COMPONENTS OF A TRANSMISSION LINE

A transmission line comprised of a system of interconnected elements, each individually designed to satisfy its respective requirements, both in technical and statutory aspects. The most robust component of a transmission line is the steel tower. The steel tower act as a support to the conductors, which are clamped to the tips of the tower crossarms by suspension or tension joints. Transmission line structures are unique compared to other structures, primarily because no human occupancy is involved and performance requirements are different than for other structure types.

Transmission towers in Malaysia are either of the lattice steel configuration comprising of angles and plates with bolted connections or single tubular poles (technically termed as monopoles) housed vertically with arched tubular arms welded to the attachments on the tower main body. Figure 1 shows the typical tower types used by the power utility company in Malaysia. Steel grades used for tower parts are a mixture of high tensile and mild steel, with all parts subjected to hot-dip galvanizing.

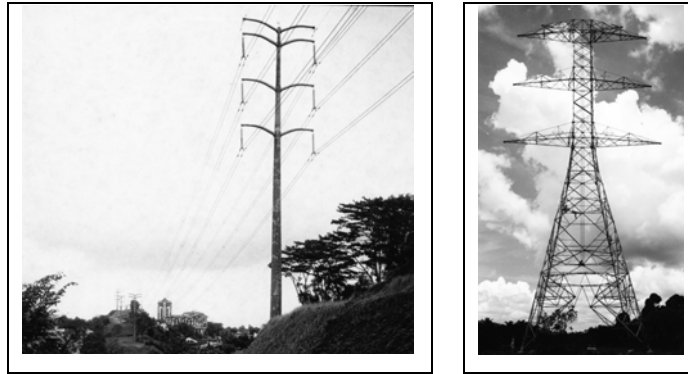


Figure 1. Typical power transmission towers (left) Monopole (right) Lattice type

Transmission towers and foundations are designed to withstand the forces resulting from wind blowing on the faces of tower steelwork and conductors, the angle pull resulting from its position on the line route, weights of conductors and accessories, unbalanced loading due to crossarm differential lengths (if any), loading condition during breakage of some specified numbers of conductors, loading condition during installation, and loading condition during maintenance of line. Figure 2 shows a sketch of the typical loadings applied to a transmission tower.

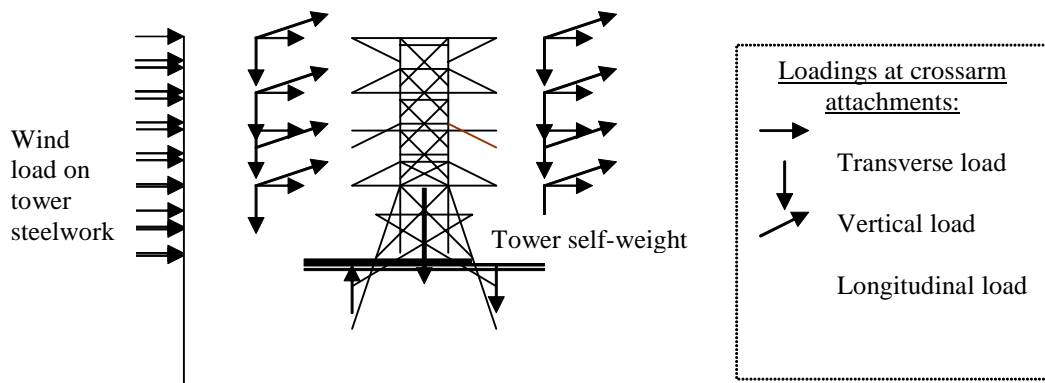


Figure 2. Typical loadings applied on a transmission tower

The component that transmit the electrical power from power plants to the load centers via the transmission lines are the conductors. Conductors comprise of aluminium strands designed to carry the electrical current, and reinforced with steel strands in the center core to withstand the pulling tension. The core of steel strands in the conductors is designed to withstand the maximum tension during cold temperatures combined with maximum wind blowing on the conductors. Unlike the temperate countries where winters can be severe, the conductor used in Malaysia is not subjected to any ice loading. The various sizes of conductors are named in accordance with international standards, except in the case where the conductor is tailor-made to the utility requirement such as the high current capacity conductor 300 sq.mm code named “Batang” conductor after the nearby town Batang Padang where it is first used in early seventies.

The set of equipment that separates electrically energized conductors and the earthed tower steelwork are the insulators. Insulators are specifically designed to withstand the high isokeraunic level in Malaysia, a country having one of the highest thunderstorm days in the world. These insulators are very delicate shells made of toughened glass or porcelain and

require care during installation to the tower crossarms. To-date, all insulators used on high voltage transmission lines in Malaysia are imported.

Other components that complete the transmission line are spacers, dampers, optical fibre groundwires (OPGW), number and phase plates, danger plate and anti-climbing device. Lightning arrestors are used on selective towers. For transmission line route in the vicinity of airports and flight paths, aircraft obstruction equipment such as sphere balls, warning lights and tower painting forms part of the required installation. Sphere balls are also installed on the lines crossing over major gas pipelines rentice.

2. TRANSMISSION LINE ROUTE CORRIDOR

Transmission line routes span cross-country, from densely populated urban areas to suburban countryside and remote virgin forest. Like highways and gas pipelines, electric power lines are linear facilities, the construction of which will require the acquisition of the right-of-way along the route earmarked by the project proponent. The provision of wayleave is stipulated in the laws of Malaysia [1]. A 275,000 volts capacity transmission line constructed on a mountaineous terrain is shown in Figure 3 (left).

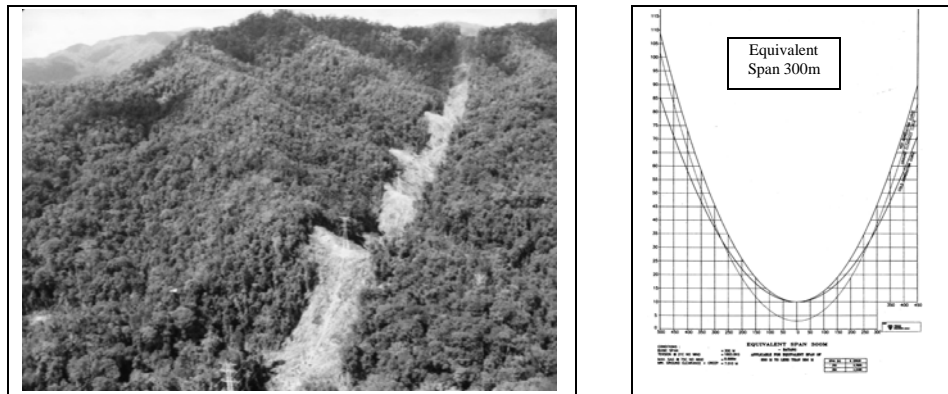


Figure 3. A 275 kV transmission line rentice in rugged terrain (left), and typical sag-curves used for tower positioning on a ground profile (right)

Prior to the identification of right-of-way, a route study is undertaken to select the optimized route in terms of technical and economic feasibility, environmental and social considerations. Factors considered in the selection of route include minimizing the cost of right-of-way, optimizing the costs for construction and maintenance, minimizing transmission losses and minimizing disturbances to the environment.

Radio and television interference, electromagnetic and electrostatic induced voltages, and audible noise are controlled through proper selection of conductors and clearances, and by using established design principles for transmission line hardware selection [2].

All equipments used on the transmission line are prototype tested in independent laboratories or test beds approved by the purchasing utility. Full-scale steel towers are assembled and type tested on rigid foundations. These galvanized structures complete with crossarms are subjected to test loads to prove compliance with the factors of safety specified by the utility [3].

Once the transmission route has been identified, a relatively high accuracy and precision survey of the corridor is undertaken to facilitate design of the transmission line. The information captured on the route plan include boundaries of the properties, utility reserves, vegetation, land use and any other features affecting the transmission line construction [4]. Profile drawings of the continuous longitudinal chainage include ground lines, line of lowest

conductor at maximum sag, indication of side slopes where these affect ground clearances of the lowest conductors on both the left and right of route centerline, and reserves of other public services.

Tower positioning on the profile drawings employ the usage of sag templates of the respective conductor ruling spans, technically termed as “equivalent span”. Figure 3 (right) shows a typical sag template for an equivalent span of 300 metres. A sag template is a scaling device used to plot towers and show the vertical position of the conductor on the ground profile. The conductor sag curves are used to graphically determine the location and height of towers based on the line design criteria. The sag templates include information on the design conditions for loading and temperature at which the sag profiles for cold and hot curves are based upon, and the governing ground clearance profile required when positioning the towers.

Upon completion of tower spotting, the locations of towers on the field are pegged with steel pipes and wooden stakes. Staking out of these structures marked the beginning of the construction phase of the project.

3. CONSTRUCTION OF A TRANSMISSION LINE

Upon completion of land survey and demarcation of trees within the reserve, route clearing is carried out with trees felled and removed from site. Bamboo clumps which are one of the main causes of line trippings are grubbed out to ensure no further re-growth possible. In addition, tall trees of such height outside the cleared area which could endanger the towers and conductors are identified, marked and cut. Felled palm trees are chipped and completely disposed of as per the requirements of the Department of Agriculture in order to curtail the breeding of the rhinoceros beetles.

The type and form of foundation used at any particular transmission tower location is decided in accordance with the established principles of soil mechanics and designed to withstand uplift, settlement, overturning and sliding when subjected to the specified conditions of tower loading. Uplift forces are usually the governing criteria for the geotechnical design (sizing) of suspension tower foundations. The foundations subjected to uplift load will depend upon the direction of wind forces blowing on the suspension tower. Uplift tests on shallow foundations, and both uplift and compression tests on piled foundations are performed in the field at selected locations along the transmission line route to verify the design and classification criteria of the respective foundation types.

Tower stubs with bolted-on anchor plates (cleats) are grouted into the reinforced concrete pad or pile caps. For coastal areas, sulphate resisting cement is used. For non-accessible locations where helicopter transport of concrete from batching plants to remote hill sites are required, retarders and plasticisers additives to the concrete are used subjected to satisfactory trial mixes.

Figure 4 (left) shows a foundation construction on a remote hill site where land transport was not feasible.



Figure 4. Foundation construction by helicopter (left), and tower erection by crane (right)

Steel transmission towers are erected manually by skilled workers using gin-poles (derricks) and pulleys. In areas accessible to cranes, the use of such equipment may expedite the erection of towers as shown in Figure 4 (right). For tower locations near the sea coast and at swampy areas, the first few metres above ground are painted with epoxy tar paint of specified thickness.

Stringing or conductor of the transmission line commences only upon completion of a minimum length of continuous stretch which would make fullest possible use of maximum conductor lengths and minimum number of conductor joints. A stringing system with tower backstays, conductor pullers and tensioners employ the use of skilled workers, very unique in their capabilities of this specialized field. Figure 5 shows a stringing site at the tensioner end. Conductor from reels are pulled and wound into the tensioner before being strung on the pulleys attached to the conductor crossarms.



Figure 5. Conducting a transmission line

Upon completion of stringing works, conductors are prestressed overnight to the required sag and clamped to the towers. Dynamometers, sighting boards, levels and thermometers are used during sagging and tensioning of the conductors.

For steeply sloping ground on hillsides, unequal leg extension or chimney extensions are used, minimizing any cuts or disturbance to the ground around the tower sites. To prevent soil erosions, disturbed ground is closely turfed with provision of drainage if necessary.

The construction scheduling of transmission lines employ the usage of simple Gantt charts for short stretches of lines to the more complex critical path method (CPM) for long stretches of lines which were divided into sections as required for fullest possible use of maximum conductor lengths, minimization of conductor tension joints and optimization on

the usage of tower types. Typical sequence of tasks with interdependence and its associated critical path method arrow diagram analysis are shown in Table 1 and Figure 6 respectively.

Table 1. Typical sequence of task for a transmission line project from Substation Y to Point Z

Activity	Duration (wks)	Inter-relationships
A: Contract Award & Kick-off Meeting	4	Independent of all other activities.
B: Check Profile Survey & Rentine Clearing	8	Dependent on completion of A.
C: Steel Tower Design & Prototype Test	12	Dependent on completion of A.
D: Sag-Tension Design & Template	6	Dependent on completion of A.
E: Standard Foundation Design	6	Dependent on completion of C.
F: Tower Spotting & Pegging	8	Dependent on completion of B, C & D.
G: Soil Inv. & Foundation Uplift Test	7	Dependent on completion of C & E.
H: Section 1 – Foundation Class & Construction	20	Dependent on completion of F & G.
I: Section 1 – Tower Erection	12	Dependent on completion of H.
J: Section 2 - Foundation Class & Construction	19	Dependent on completion of F & G.
K: Section 2 – Tower Erection	12	Dependent on completion of J.
L: Section 3 – Foundation Class & Construction	24	Dependent on completion of F & G.
M: Section 3 – Tower Erection	10	Dependent on completion of L.
N: Stringing, Sagging & Tensioning	8	Dependent on completion of I, K & M.
P: Line Test & Commissioning	4	Dependent on completion of N.

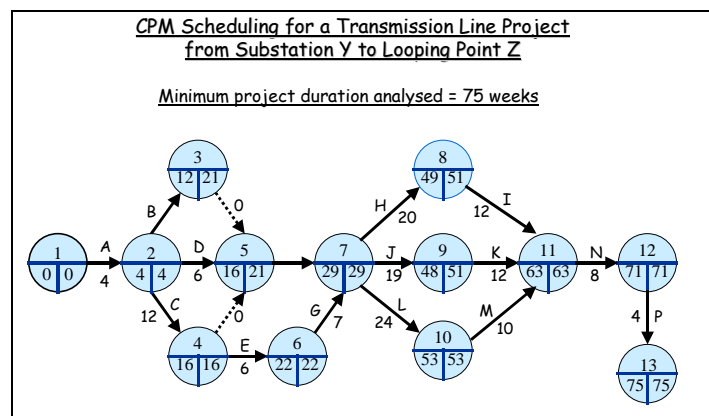


Figure 6. Typical simplified network analysis arrow diagram for a transmission line project

4. MANAGING THE CHALLENGES

The major issues that confront utilities from the smooth implementations of power transmission line projects and the challenges facing these organizations for a sustainable construction and planned project management scheduling can be summarized into the following subject matters:

4.1 Sustainability of rentice

In Malaysia, land matters are under the authority and jurisdiction of the state governments. For a transmission line rentice, compensation is given to the individual or commercial landowners on the basis of a right-of-way. Ownership of the land is still with the respective owners. Delays to transmission line project occurs when property owners cannot be located, in residence overseas, deceased with unsettled transfer of ownership, land under lease or sublease, and delays by small industries on dismantling and re-location of the premises affected.

Updated information on areas for development such as the provision of new airports, extension to existing airports, and expansion of river or road reserves will avoid any overlapping of new transmission line rentice with other gazetted reserves. The areas identified as aboriginal settlements both at suburban and remote locations is an important information to be made known to the power utility in the planning and implementation of a transmission line project. The role of state land administrators and relevant government agencies, and the coordination between the power utility with these agencies on the provision of the right-of-way as per the Electricity Supply Act 1990 [1] is an important factor on the timely implementation of a transmission line project.

Stolen tower parts, even redundant bracing members, cause tower instability, buckling of main legs resulting from inadequate slenderness ratios of the steel member, and eventual collapse of the towers. The effects of tower collapse for a new transmission line project under construction can be aggravated if there are energized high voltage lines running in parallel. Livestock and properties would also be damaged as experienced in several similar occasions which have made newspaper headlines.

Towers are positioned with sufficient electrical and ground clearances as required by regulation [1]. For hilly to undulating ground, towers are typically positioned on hilltops to achieve the stipulated clearances. Earth quarry or similar development of land within or near the rentice may result in reduction to the factors of safety of the slopes adjacent to the tower locations. As land matters are under the jurisdiction of state land authorities, utility company that build and maintain the power transmission line can only trigger information to the land authorities concerned. However, continuous inspection of the affected sites and soil erosion controls are required to be performed for mitigations against further slope failures.

4.2 Constraints on supply of components

In 1998, the local power utility in Malaysia imposed a ruling to its vendors that all steel transmission towers, conductors, fittings and optical fibre groundwires to be sourced from local manufacturers. Exception was only given to high voltage insulator disc to be imported as there was no local industry manufacturing such item; insulator still remain an imported item today. For a few years after the ruling, the constraints on the availability of locally manufactured and fabricated steel towers have greatly affected the critical path sequence of a transmission line construction schedule. The scenario has improved but local industries are not void of difficulties in meeting the demand for the correct size, thickness and grade used for the tower main leg members and plates, especially on the heavier tower types.

The first and only tower testing station available locally commenced operations in early 2000 near Kuching, Sarawak. Local power utility company, Tenaga Nasional Berhad, has also done away with using chengal timber crossarms on their suspension towers, instead adopted the use of steel for new towers to be installed in their system. Chengal timber has been used ever since the sixties in the National Grid system due to their technically desirable insulation properties.

4.3 Logistics and supplies

The movement of heavy equipment on rugged terrain has been a major challenge to the vendors of transmission line projects. For a long stretch of transmission route traversing across mountaineous areas which requires the use of both land and helicopter transport, the construction of temporary base camps at strategic locations, storage yards for material in transit, and the provision of batching plants for concrete mixing are essential requirements. Base camps housing the skilled and general workers are equipped with sufficient food and medical supplies to sustain long periods of inclement weather conditions. The use of the correct proportions of plasticiser (retarding additives) into concrete for a timely aerial transport of concrete from batching plants to the tower locations are the main concern of this unique mode of construction practice.

More than often tower parts and delicate materials such as porcelain and glass insulators were damaged by mishandling or by wild animals. Thefts and vandalism on steel tower parts, copper earth rods and aluminium clad conductors are also becoming more frequent, especially with the rising market value of these metals. The movement of heavy transmission line equipment and piles across swampy and water logged areas employ the use of land vehicles with modified wheels or special pontoons for lakes and open swamps. Construction of the transmission lines across mountaineous terrain and swamps requires delicate handling of equipment and properly managed logistics to minimize damages to the environment.

5. CONCLUSION

Transmission line engineering and construction practice is a specialized technical field which requires the principal knowledge and skills on transmission component design, manpower and material management, sequence of tasks, logistics and a comprehension of the statutory regulations pertaining to its right-of-way.

Scheduled completion of a power transmission line project could only be achieved when the challenges involving logistic activities throughout the planning and implementation stages are strategically managed within the constraints of the local environment.

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